

# Exploring effects of position-related information on the perception of scenario-based passing opportunities: An information integration theoretical approach

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## ABSTRACT

When football players are preparing to pass the ball, they consider contextual information provided by the current game situation to identify passing opportunities and choose the one that appears most beneficial. In the search for contextual information indicating such opportunities, a recent study analyzing the relationships between the position-related characteristics of game situations and athletes' passing behavior reports that athletes generally prioritize passing options based on their team members' areal proximity, the openness of the passing lanes leading to team members, and how closely the team members are covered by the opponents. While the found relationships indicate the positional features' relevance to the athletes' passing behavior, the importance of single bits of positional information and their integration into subjectively perceived passing opportunities remain unknown. The aim of this study is to begin closing this gap and analyze how multiple athletes weigh and integrate position-related information within their subjective process of perceiving passing opportunities.

The study uses a 3x3x3 within-subject design. Twenty-one football players provided information about the perceived quality of passing opportunities within standardized game scenarios. The data were analyzed using an information integration theoretical approach combined with mixed linear modeling. The results reveal substantial interpersonal differences regarding the importance players attribute to specific positional information and how they integrate the positional information. Two recurring patterns of information integration were found. In most of the cases, the results indicate linear information integration. However, in some cases, the results indicate that players deviate from linear information integration when a single piece of positional information seemingly dominates the athletes' perceptions. In the future, IIT approaches can be adopted to research designs using virtual reality, including other sets and ranges of contextual information, as well as other sports and sports situations in which the integration of information into subjective perceptions is of interest.

### Keywords:

contextual information – environment – visual information – soccer – affordance

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## Introduction

Passes are a performance-relevant, constitutional part of football and most other interactive team sports (e.g., Evangelos, Aristotelis, Ioannis, Stergios, & Foteini, 2014; Reed, 2004). They are played within game contexts that change depending on the positions of the ball, team members, and opponents (Vilar, Araújo, Davids, & Button, 2012). In the specific case of football, most passes cannot be planned in detail very far ahead of the players' involvement within specific game situations. Hence, players must consider the current contextual circumstances, check for available passing opportunities, and choose amongst those that appear beneficial for their team's performance. To develop an understanding of the kinds of contextual circumstances that indicate such opportunities, studies inspired by ecological perspectives (Gibson, 1977; Araújo, Davids, & Hristovsky, 2006) have begun to analyze the relationships between current game environments and athletes' passing behavior. In short, ecological perspectives take the view that behavior and decision-making are strongly influenced by the use of environmental information (Araújo et al., 2006). Finding recurring patterns of interaction between players and their game-related environment is, thus, considered a way to determine the kinds of information relevant to choosing specific behavior (e.g., Passos, Cordovil, Fernandes, & Barreiros, 2012; Barsingerhorn, Zall, De Poel, & Pepping, 2013; Da Silva et al., 2017). Adopting an ecological approach, Steiner, Rauh, Rumo, Sonderegger, and Seiler (2018) analyzed passes played in naturally occurring game situations. Comparing the positional features of team members receiving a pass to those of team members that did not indicates that athletes generally prioritize passes based on their team members' areal proximity, the openness of the passing lanes leading to team members, and how closely the team members are covered by the opponents. Assuming that the perception of passing opportunities precedes the athletes' passing decisions (e.g., Fajen, Riley, & Turvey, 2009) and that athletes pick the opportunities deemed most worthy or most likely to be successful (Araújo et al., 2006; Beek, 2009), the results indicate how position-related information could be involved in this perception process. However, since no direct measure of subjective perception is included in Steiner et al.'s (2018) study, the contribution of different kinds of positional information within the subjective process of perceiving passing opportunities remains to be tested.

The lack of research on athletes' use of context-related information has been pointed out repeatedly. Araújo and Bourbousson (2016) remark that interpersonal behavior (e.g., passes played between athletes) is often assumed to be led or facilitated by the perception of contextual information, but data-based findings are scarce. In the context of research on anticipatory behavior, Cañal-Bruland and Mann (2015) summarize previous research as having highlighted the surprisingly large role of contextual information. They also note that little is known about how athletes use and integrate contextual information. These points similarly apply to research regarding the perception of passing opportunities. While potentially relevant sources of contextual information have been located (Steiner et al., 2018), nothing is known about the weighting

of single pieces of information or how athletes integrate multiple informers within the process of perceiving passing opportunities. Cañal-Bruland and Mann (2015) discuss various ways in which the integration of contextual information could take place; athletes may rely on the most prominent source of information, or they may combine several sources of information additively (linearly) or in a way in which interaction between different informers occurs (non-linearly). Examples of multiple informers interacting with each other are multiplicative information integration or the perception of a 'gestalt' (Kofka, 1935). In both cases, the subjective meaning of a specific source of information changes depending on the presence of another source of information (Anderson, 1996). Cañal-Bruland and Mann (2015) further consider that various athletes may adopt different strategies in their use of contextual information within identical game scenarios.

This last consideration is of interest with regard to another finding from Steiner et al.'s (2018) study. Despite the overall correlations between the contextual features and the total sample of the analyzed passes, there were a considerable number of passing decisions that did not seem to follow this correlational pattern. The authors argued that individual differences regarding the subjective use of contextual information and the importance the different kinds of information receive within the process of perceiving passing opportunities could be a possible explanation to this finding. However, in a study that is based on a sample of passing decisions made by various athletes in unique game situations, other contextual features than the ones considered or the different positions of the athletes passing the ball are all inextricably confounded with possible idiosyncrasies in the perception and selection of passing opportunities. In this study, we will reduce this confounding of variables in order to analyze the hitherto unexamined weighting and integration of positional information within the process of athletes perceiving passing opportunities and to test for possible idiosyncrasies within it. Our research questions refer to 1a) how multiple sources of positional information contribute to athletes' perceptions of passing opportunities and 1b) whether athletes differ regarding the importance they attach to positional information within the process of perceiving passing opportunities, as well as 2a) whether there are recurring patterns in how athletes' integrate positional information into perceived passing opportunities indicative of a centering-type, linear, or non-linear information integration and 2b) whether athletes differ regarding how they integrate positional information into perceived passing opportunities.

Analyzing the process of multiple contextual informers being integrated into perceived passing opportunities and testing for potential interpersonal differences requires special methodological approaches. First, a sound analysis and comparison of various athletes' information integration processes require a standardized presentation of the information to be integrated. Second, the approach must be able to detect the potentially differing integration patterns of various individuals. Some standard statistical procedures do not meet this requirement because their parameter estimation functions based on a priori assumptions regarding a general relationship between independent (the position-related

information) and dependent variables (the perceived passing opportunity) across the analyzed sample. In this study, we adopt methods developed within the framework of information integration theory (IIT; Anderson, 1981) in combination with mixed linear modeling (MLM). IIT's measurement concept is based on the controlled manipulation of multiple informers, of which the integration into a subjective perception is of interest. In so-called full factorial designs (Anderson, 1982), pre-selected values of multiple information dimensions are exhaustively combined to test their effects on how athletes perceive passing opportunities. The athletes' perceptions can then be analyzed backwards to eventually isolate the effects of single informers and approach the underlying information integration inductively. MLM can differentiate between the data of multiple athletes during parameter estimation and, hence, test whether specific parameter estimates differ between athletes. Further details regarding the specific procedures are provided in the following section.

## Methods

Twenty-one male football players ( $M = 25.38$  years,  $SD = 3.83$ ) participated in the study. The players were recruited from two football teams playing at the second and third highest level of the Swiss Football League. They had been playing football for an average of 18.81 years ( $SD = 4.53$ ). All participants gave written informed consent in accordance with the Declaration of Helsinki. The study's protocol (Nr. 2018-03-00003) was approved by the Ethics commission of the Faculty of Human Sciences of the University of Bern.

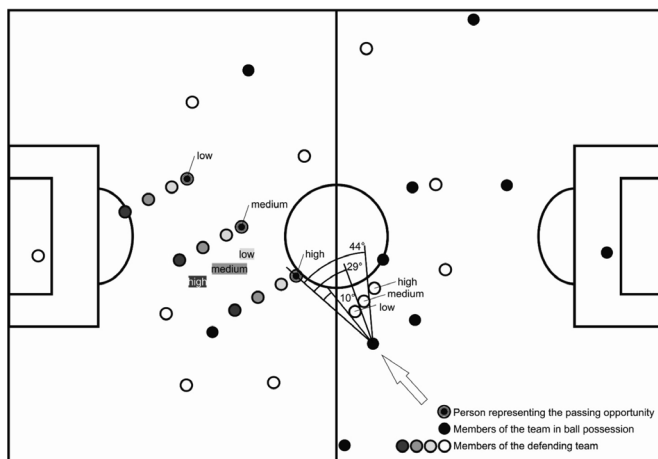
### Procedures

In a 3x3x3 full factorial within-subject design (Anderson, 1982), each participant rated all 27 passing options resulting from the combination of three values in each of the passing opportunity's position-related factors (i.e., openness of the passing lane, defensive coverage, distance from the ball carrier). A scene taken from a game at the 2014 FIFA World Championship served as the initial situation for this study's stimulus situations. The game situation was graphically recreated using CorelDRAW (Version 7). The player receiving the pass during the real game represented the passing opportunity on which participants were instructed to focus. The openness of the passing lane leading to this player, the tightness of the defense by the opponent defending him, and the player's distance from the ball carrier were manipulated. For each variable, three values (i.e., low, medium, high) were defined. According to IIT, the stimulus values representing the low, medium, and high values should "cover some substantial range with roughly equal spacing" from each value to the next (Anderson, 1982, p. 67). It should be mentioned that only approximations to equal spacing are possible. This is because the distance between two stimulus values should be determined on the basis of the different *effects* the two stimulus values have

on the subjective perception of a passing opportunity (e.g., a subjective unit) and not just the difference in the stimulus' physical values themselves (e.g., an objectively determinable distance in meters). In defining the spacing between the low, medium, and high values of each variable, we considered the empirically determined effects the same variables had on passing decisions in real-world game situations (Steiner et al., 2018). Steiner et al. reported that the probability that a player carrying the ball would pass it to a team member related linearly to that team member's distance from the ball carrier and how closely that team member was defended. Taking these results as a reference, defining the low, medium and high values of the two mentioned variables could be done by simply augmenting their physical values by equal amounts from each value to the next. In determining these values for the distance variable, we considered existing literature for indications of what could be considered a short and a long pass, respectively. We determined a value for both the low and the high value that would fit the definitions used in the studies of Aquino, Puggina, Alves and Garganta (2017), Liu, Gomez, Lago-Peñas and Sampaio (2015), Rampinini, Impellizzeri, Castagna, Coutts, and Wisløff (2007), Rampinini, Impellizzeri, Castagna, Azzalin, Ferrari, and Wisløff (2008), and Tenga, Holme, Ronglan, and Bahr (2010). When linearly interpolating the distances in the game scenario, we assumed the playing field to have a standard length of 105m. The value for the medium distance was set to be the exact center point of the two other values. For the defensive coverage, we did not find any reference from which to deduce distances that would indicate tight, medium or loose defense by opponent players. In order to determine the three values, five male soccer players ( $M = 24.80$  years,  $SD = 1.10$ ) were shown the game scenario in which the pass receiver was at a medium distance and asked to indicate what they would consider being a tight, and what they would consider being a loose defensive coverage in the given situation. Their position markers were averaged and used as low and high stimulus values of the defensive coverage variable, respectively. As was done with the distance variable, the medium stimulus value was set to be the exact center point of the two other values.

Besides the linear relationships found between each of these two variables and the passing decisions, Steiner et al. (2018) report that passing decisions did not relate linearly to the openness of the passing lanes to team members. This means that the probability of a team member being passed the ball did not augment linearly with the angle between the passing lane to that team member and the opponent player nearest to this passing lane becoming larger. Consequently, the low, medium, and high values for the passing lane variable had to be determined based on the reported probability of a pass being played to a team member at a given level of openness. Some intermediate steps were necessary. Steiner et al. (2018) measured the openness of the passing lane from the ball carrier to each of his team members in angular degrees (step 1) to determine minimum and maximum values in each game situation (step 2). They then standardized the measures to values between zero (e.g., the least open passing lane within a game situation) and nine (e.g., the most open passing lane within that same game situation; step 3). The quintile transformation carried out

afterwards split the variable into five value ranges determining five categories of this variable that were then statistically contrasted against each other and for which Steiner et al. report relative probabilities for passes. The cutoffs of the five categories are 0.29, 1.10, 2.52, and 5.67 (Steiner et al., 2018, p. 4). We first performed steps 1 to 3 within the game situation from which we derived this study's stimulus situations. The cutoffs were then used to linearly interpolate the value ranges corresponding to categories 1 to 5 in Steiner et al.'s (2018) study. Aiming at stimulus values that are at an approximately equally spaced distance from one value to the next, we chose angles that correspond to categories 3, 4, and 5 with relative passing probabilities of  $\beta_{\text{cat}3} = 0.3$ ,  $\beta_{\text{cat}4} = 0.8$ , and  $\beta_{\text{cat}5} = 1.4$ , respectively (see Steiner et al., 2018, p. 4, table 1). The low, medium, and high values were  $10^\circ$ ,  $29^\circ$ , and  $44^\circ$ , respectively. Figure 1 illustrates the 3x3 passing opportunities used in the study.



**Figure 1.** Graphic summary of the passing situations used in the study. The arrow indicates the person with the ball. The labels 'low', 'medium', and 'high' indicate the positions used in operationalizing the three values in each of the factors 'openness of passing lane', 'defensive coverage', and 'distance from ball carrier'.

Five versions of the questionnaire with a randomized order of the passing opportunities were used. The participants were instructed to take the perspective of the ball carrier (indicated by an arrow) and indicate the perceived quality of the depicted passing opportunity<sup>1</sup>. The answers were provided on visual analog scales (VAS) ranging from 0 (not at all a good passing opportunity) to 10 (a very good passing opportunity). Since the ratings of the 27 passing opportunities are comparative, a stable frame of rating reference needed to be established before data collection (Anderson, 1982, 1996). To achieve this, the participants completed practice situations prior to working on the actual test trials. The use of end anchors was the first step in the process of setting up correspondence between the subjectively perceived quality of a passing opportunity and the external response scale (e.g., the VAS). Two of the shown passing opportunities in the

practice phase were more extreme than the regular experimental passing options. These end anchors were used to define the range of the rating scale (Anderson, 1996). The process was continued with the presentation of practice situations that covered the range of the regular experimental passing situations. These practice procedures contribute to a perception-response calibration that enables a stable usage of the rating scale already at the start of the actual run (Anderson, 1982). After the practice situations, the participants worked on the 27 situations. The cover story informed the participants that the game was in the 80<sup>th</sup> minute, the score was 1:0, and their team was ahead.

### Data analysis

To check whether the manipulation of the three values (i.e., low, medium, and high) in each of the three factors affected the perception of the passing opportunity as intended, we specified a general linear model for repeated measures. The model included the three-stage factors (i.e., openness of the passing lane, defensive coverage, and distance from the ball carrier) as predictor variables. The perceived quality of the passing opportunity was the dependent variable. A significant coefficient estimate for a factor would indicate that changes in that factor affect the perceived quality of the passing opportunity and that the manipulation is successful.

To answer the question of whether the three factors had similar effects on the perception of a passing opportunity across multiple athletes, we specified an MLM with the same three-stage factors and dependent variable. The participants were used as a cluster variable on the second level and the factors were specified as random effects. Thus, the model accounts for the dependency of all ratings made by the same participant and estimates the regression coefficients individually for each player. A significant random effect would indicate that the size of the estimated coefficient varies across players, or, in other words, that changes in the openness of a passing lane, defensive coverage, and distance from the ball carrier affect the perception of a passing opportunity differently across players. The mixed linear model was estimated with maximum likelihood (ML) and restricted maximum likelihood (REML) to gauge the results' dependency on the estimation method.

To explore the integration of the positional information into perceived passing opportunities, we plotted each players' data as a function of all value combinations in the three variable pairings to obtain individual IIDs. To ease the interpretation of these diagrams, they are two-dimensional; the effects of the three values in each of the two factors on the players' perceptions are averaged over the three values in the third factor (Anderson, 1981). The data courses in these IIDs can be interpreted regarding the underlying information integration. According to Anderson (1981), parallelism in the data courses is indicative of an additive-type information integration. Linear fan patterns indicate multiplicative information integration. If multiple passing opportunities are identical regarding their

<sup>1</sup> This reduction of a subjectively perceived passing opportunity on a one-dimensional scale is a necessary simplification within the IIT approach to make the effects of different informers comparable on a uniform scale (Anderson, 1996).

value in one positional feature (but different regarding either of the other two) and are perceived in an unchanged manner, then this would indicate that the specific informer is perceived as the most prominent source of information, dominating an athlete's perception of the passing opportunity. Other IID patterns are also conceivable and could, among other things, be indicative of athletes perceiving passing opportunities configurally as a 'gestalt' (Kofka, 1935).

In the case of seemingly parallel data courses, the parallelism can be tested statistically (Weiss, 2006). This test includes the specification of interaction terms between any two predictor variables. Significant interaction terms indicate a change in the effect of one positional informer depending on the value of the other one (Anderson, 1981). This meaning change as a function of the presence of other information would argue against linear information integration. Depending on whether the information integration is similar across all players, the tests can be performed with the total sample or must be performed separately for each individual (Weiss, 2006).

## Results

The manipulation check yielded significant effect estimates for the following factors: openness of the passing lane ( $F[1.23] = 67.92$ ,  $p < .001$ ), defensive coverage ( $F[1.25] = 103.96$ ,  $p < .001$ ), and distance from the ball carrier ( $F[1.25] = 10.19$ ,  $p < .01$ ). In the total sample, the perceived quality of a passing opportunity increased as the passing lane to the team member became more open, as the team member was less closely defended, and when the team member's distance from the ball carrier was short. The manipulation of the three values in each of the factors was successful.

Mixed linear models require that the residuals remaining after controlling for the effects of the predictors are normally distributed (Snijders & Bosker, 2012). This requirement was met. Running the MLM with ML and REML estimators yielded highly comparable results. We present the results of the REML, which produces more accurate estimates of random effects (Twisk, 2006). The results are shown in Table 1. The estimates of the fixed effects confirm the results of the manipulation check. They also indicate the changes in

**Table 1.** Fixed effects estimates (top) and variance-covariance estimates (bottom) of the positional information on perceived passing opportunities.

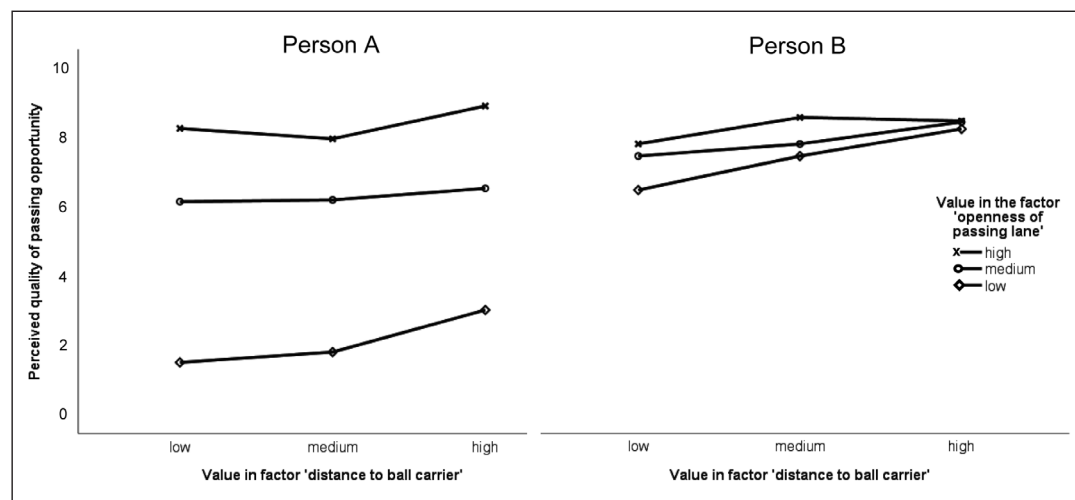
Parameter	$\beta$	Test statistics	CI 95%
<b>Fixed effects</b>			
Passing lane		50.872***	
medium vs. low	0.724 (0.358)	2.023	-0.006; 1.454
high vs. low	3.425 (0.358)	9.570 ***	2.694; 4.155
Defensive coverage		81.516***	
medium vs. low	1.544 (0.332)	4.652***	0.865; 2.222
high vs. low	4.190 (0.332)	12.624***	3.511; 4.868
Distance		9.564***	
medium vs. low	0.606 (0.177)	3.413**	0.246; 0.966
high vs. low	0.723 (0.177)	4.075***	0.363; 1.083
Intercept	9.215 (0.360)	25.588***	8.502; 9.929
<b>Level 2</b>			
<b>Random effects</b>			
var $\beta_{pa\_lane}$	1.182 (0.345)	3.430***	0.667; 2.093
var $\beta_{de\_cov}$	0.994 (0.302)	3.288***	0.547; 1.804
var $\beta_{distance}$	0.168 (0.079)	2.115*	0.066; 0.424

Note: Standard errors are in parentheses.  $pa\_lane$  = openness of passing lane;  $de\_cov$  = defensive coverage. var = variance.

Test statistic for the main effects = F-value, for contrasts between categories of a factor = T-value, for the variance parameters = Wald Z-value.

\*\*\*  $p < .001$ , \*\*  $p < .01$ , \*  $p < .05$





**Figure 2.** IIDs showing interpersonal differences in how much changes in the openness of the passing lane affect the perceived quality of passing opportunities.

the perceived quality of a passing opportunity as a function of the passing opportunity's value in each factor. For example, compared to the team member being tightly defended, the perceived quality of the passing opportunity increased by 1.54 units when the defense was at the medium value (contrast medium vs. low). It further increased as the team member was defended even more loosely (contrast high vs. low). The significant random effects ( $\beta$  variance) indicate inter-individual differences in how the three factors affected the players' perception of the passing opportunities. The two IIDs in Figure 2 exemplify such interpersonal differences.<sup>2</sup> For Player A, the maximum distance between the three data lines is larger than for Player B. This means that the changes in the openness of the passing lane had a stronger influence on Player A's perception of the passing opportunity than on Player B's perception.

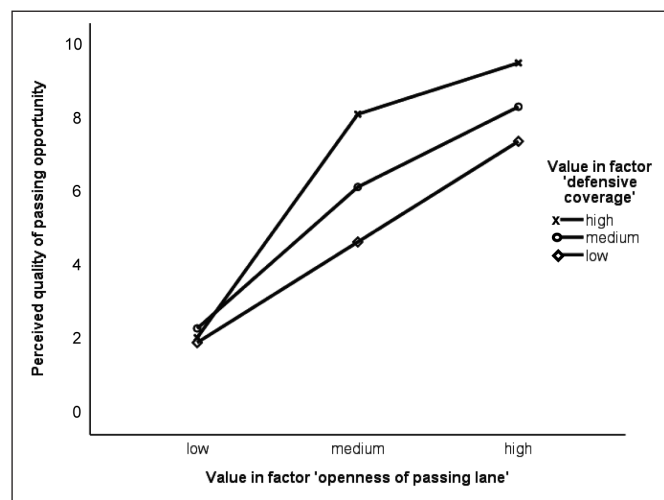
A primary visual inspection of each player's IIDs revealed differences in the IIDs of different players. It is important to note that these differences do not (only) refer to the interpersonally different effects single factors had on perceived passing opportunities (e.g., the significantly different  $\beta$  values exemplified in Figure 2). Rather, they refer to differences in how position-related informers interact (or don't interact) with each other within the process of a player perceiving a passing opportunity. The data courses in some players' IIDs seemed to follow parallelism, indicating a linear way of integrating the positional information. Those of others, however, seemed to substantially deviate from parallelism, indicating non-linear information integration. Due to these interpersonal differences, statistical testing of parallelism was performed separately for each individual.

Seven of the 63 (21\*3) interaction terms specified were significant. This rules out parallelism statistically and indicates that the athletes did not integrate the two involved sources of information linearly.

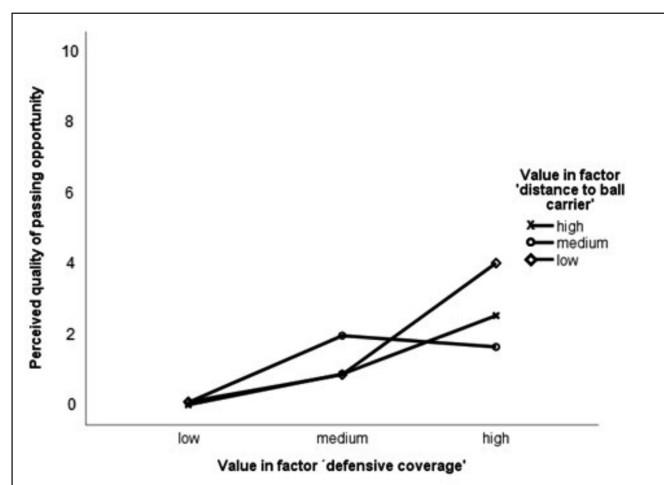
All 7 concerned IIDs were again inspected. In three of them, we found that the deviation from linear information integration could be attributed to a single piece of positional information, which, if present, seemed to dominate the perception of the passing opportunity. In one of these cases, a tightly defended passing lane was the dominant piece of information. In the two other cases, the potential pass receiver being tightly defended seemed to be the dominant piece of information. In these three cases, the other information dimension characterizing the passing opportunity appeared to have a reduced effect on the athletes' perception of the passing opportunity; the perceived quality of the passing opportunity altered little despite changes in the value of the other position variable. An example IID is illustrated in Figure 3. To test whether the low variable values could indeed be responsible for the found non-linearity, we re-analysed the data of the three IIDs concerned. This time, however, we excluded the passing situations that showed the positional information we assumed to be responsible for the non-linear information integration. After exclusion, no significant interaction terms were found, indicating that the remaining information was integrated linearly.

The remaining four diagrams indicating non-linear information integration were all unique and did not seem to follow a common integration pattern. It is worth mentioning, however, that all four diagrams involved information about the distance of the potential pass receiver from the ball carrier, twice in combination with the defensive coverage and twice in combination with the openness of the passing lane. An example IID is shown in Figure 4. The IID reveals that the athlete perceives well-defended team members as not a good passing opportunity, regardless of how closely the team members might be located. Information about the team member's distance then affects the perceived passing opportunity differently depending on whether the team member

<sup>2</sup> The effects of the factors openness of passing lane and distance to the ball carrier on the players' perceptions are averaged over the three values in the factor defensive coverage. The different distances between the three data lines in the two IIDs indicate how changes in the openness of the passing lane affected these athletes' perceptions of the passing opportunities to different degrees.



**Figure 3.** IID indicating a dominant role of the information about a well-defended passing lane (low). The perceived quality of the passing opportunity does not change despite changes in how tightly the team member representing the passing opportunity is defended.



**Figure 4.** IID indicative of non-linear information integration; the data courses deviate significantly from parallelism.

is defended at a medium or loose level (corresponding to medium or high value of the defensive coverage factor, respectively). When the team member is defended at the medium level, the passing opportunity is perceived as best when at a medium distance from the ball carrier. The relationship changes when the team member is defended at the loosest level; the athlete perceives the quality of the passing opportunity to be best when loose defence combines with a farther distance, lower when loose defence combines with a near distance, and lowest when loose defence combines with a medium range distance. Interpretations of the found patterns are discussed in the next section.

## Discussion

The goal of this study was to explore athletes' use of three types of contextual information in the process of perceiving passing opportunities and to test whether players differ from each other regarding the importance they attribute to specific positional information, or the way they integrate it into an overall perceived quality of the passing opportunity. Overall, open passing lanes, loose defense by opponents, and positions in areal proximity to the ball carrier increased the perceived quality of passing opportunities. Besides these overall effects, we found substantial interpersonal differences as players differed regarding the importance they attributed to specific positional information when perceiving passing opportunities. For example, while some players perceived the quality of a passing opportunity primarily as a function of the openness of the passing lane to a team member, the same source of positional information had a far smaller effect on how other athletes perceived the quality of passing opportunities. Interpersonal differences were also found when considering the integration of positional information into perceived passing opportunities. We observed two recurring patterns. For most athletes and most pairs of positional information, the patterns indicated that athletes combined the positional information linearly, in an additive-type manner. The second pattern was detected among data courses indicating no linear information integration. Here, the deviations from linear information integration could be attributed to a single informer which, if present, seemed to dominate the subjective perception of the passing opportunities. Four cases in which nonlinear information integration was observed did not show a uniform pattern and therefore, could not be classified into a common category of underlying information integration.

Before discussing the results in greater detail, we shall point to some shortcomings of this study. First, the results are based on a low sample size including 27 variants of one static game situation. As such, the results are only representative for the investigated game situation, which limits their implications. Second, the study analyzes passing opportunities within static game scenarios presented from a top-view. Obviously, this differs from how players perceive passing opportunities in real games. While previous results from studies using the same kind of game scenarios have been shown to generalize to real world settings (see Steiner, 2018; Steiner et al., 2018), the generalizability of the present results remains unclear until tested in ecologically more valid settings (e.g., virtual reality [VR] environments). Third, within the framework of the IIT approach used, the players' attention is directed to one selected passing opportunity. It is known that athletes adopt different perspectives of the current game and that the narrow attentional focus induced by the approach used does not correspond to how players perceive all the various situations occurring throughout a competition (Feigean, R'Kiouak, Seiler, & Bourbousson, 2018). For example, analyzing how athletes perceive a selected passing opportunity is different from analyzing how they perceive that passing opportunity relative to other, simultaneously available passing opportunities. This difference should be borne in mind when we later compare the findings of this study with those

of previous ones, all of which adopted the latter approach. Fourth, reducing the perception of a passing opportunity to a measure on a one-dimensional scale representing the perceived quality of that passing opportunity is a simplification that omits much of importance. However, the reduction is an integral part of the IIT methodology applied here and should be considered against the background of what it enables, namely an analysis of how multiple informers are integrated into a subjective perception. Fifth, unlike in real competition settings, the response time for players was not constrained. Potential effects of time constraints on how players weigh and integrate positional information when perceiving passing opportunities remain to be tested.

To date, there are three studies available which report relations between openness of passing lanes, areal proximity, defensive coverage and passing decisions and which can be considered as references to discuss the present findings (Steiner, 2018; Steiner et al., 2018; Steiner et al., 2019). Overall, these studies hint to the relevance of the positional variables to passing decisions as a substantial number of the passes analyzed shows significant correlations with the three positional variables. The two studies that present estimates for the relationship between the total sample of passing decisions and all three positional variables further report that areal proximity was the strongest predictor, indicating that this positional feature had the overall highest impact on the athletes' decisions about whom to pass the ball (Steiner, 2018; Steiner et al., 2018). No consistent findings with regard to the effect ranking of the other positional features were reported. While these previous results led us to expect that the three position variables would influence the perceived quality of the passing opportunities in this study, the inconsistencies regarding the effect size ranking led us to restrain from formulating specific hypotheses on the relative effects of the three variables. That said, the comparatively weak effect of the distance variable on the perceived quality of the passing opportunities came as rather unexpected. We shall discuss a possible explanation for this result. Unlike in classic work using IIT (e.g., Anderson, 1962), positional variables within the context of football situations cannot be manipulated completely independent of each other, that is, without affecting the game situation of which they are all a part. In the used situations, increasing the distance of the athlete representing the passing opportunity also changed this athlete's absolute position on the playfield (e.g., his position relative to the opponent goal). It has been argued that the team members' closeness to the opponents' goal represents positional information that discloses the goal-approximative consequences to be expected after a corresponding pass (Oesterreich, 1981; Steiner 2018). A closer positioning to the goal could therefore add to the perceived quality of a passing opportunity. While the increasing distance of a team member generally lowered the perceived quality of the passing opportunity he represented, his shortened distance to the opponent's goal is a confounding factor that could have counteracted the effect of the increased distance and, hence, could be a reason for the comparably weak effect of the distance factor found in this study. Obviously, this explanation remains hypothetical at this point as it cannot be further verified on the basis of the data presented here. Testing the plausibility of

this explanation could include multiple game situations, in each of which the same three variables are being manipulated to render separate 3x3x3 designs. If our interpretation holds, weaker effects of the distance factor should be found in game situations in which the farther distance of a player coincides with a closer position to the goal than in game situations in which the farther distance of a player does not mean an additional approach to the goal (as would be the case with a cross pass, for example).

The three sources of positional information that increased the perceived quality of passing opportunities in this study had previously been reported to generally increase the passing opportunities' probability of being passed the ball (Steiner et al., 2018). Obviously, the findings of the two independent studies are not direct support for the idea of passing decisions being mediated by how athletes perceive given passing opportunities. However, considering the results of this study, the idea maintains its plausibility. Besides the overall relationship between the positional features and athletes' passing decisions, Steiner et al. (2018) reported that 6% of the passes were played to passing opportunities which, based on their positional features, were predicted to be among the three least probable passing opportunities within the given game situations. The authors discussed idiosyncrasies in the way athletes perceive passing opportunities as one possible explanation for the deviant passing decisions. The found differences in how multiple athletes weigh and integrate contextual information when perceiving passing opportunities allow to maintain the plausibility of this first explanation. The implication for future research is that how the perception of passing opportunities actually mediates passing decisions by considering both perception and decision measures within the same study should be analyzed. Given that individuals differ regarding the perception of passing opportunities and the kinds of information most relevant to this perception, our hypothesis is that the prediction rate of passing decisions will be improved if purely objective variables about current positional features are complemented (or replaced) by the athletes' subjective perspectives of given passing opportunities. As another explanation, Steiner et al. (2018) implied that additional sources of information affecting the passing decisions could be accountable for the deviant passes and that these should be determined and controlled for. For example, they reported that, when analyzed separately, passes played in the attacking third did not significantly relate to how loosely team members were defended and that considering more such positional variables might help improve the prediction rate (Steiner et al., 2018). The fact that we did not consider additional variables within the experimental design does not mean that we do not consider them potentially influential. Rather, our primary aim was to experimentally test the integration of the three previously considered types of positional information under otherwise constant conditions (e.g., the zone of the person passing the ball, the time and score of the game, and the positions of other opponents and teammates). As a side note, work using IIT does usually not assume that the considered types of information are the only information relevant to a perception, an impression formation, or whatever else is at the focus of an investigation.



Instead, it tries to approach the patterns underlying the integration of the selected types of information. While the methodological approach enabled to detect idiosyncrasies in the perception of passing opportunities, we are currently left to speculate about the causes of these interpersonal differences. Different game plans, different playing strategies, different mind sets from which the athletes viewed the game situations come to mind as variables at the level of the perceiving athletes. However, further investigations are necessary to provide additional insights here.

The two recurring patterns of data courses found in the IIDs can be interpreted as being in support of two of the combination rules outlined by Canal-Bruland and Mann (2015), namely additive information integration and integration ruled by the dominance of one specific piece of information. In three cases, the presence of a specific piece of information seemed to dominate the perception of the passing opportunities, indicating a subjectively prominent role that information had in the perception process. When the passing opportunities including the seemingly dominant piece of information were omitted from the analyses, the integration patterns no longer showed significant deviation from parallel data courses, indicating a linear integration of the remaining contextual information. Our interpretation (and a hypothesis for future research) is that additive information integration occurs when the positional informers to be integrated are above subjectively critical thresholds. If a positional informer falls below this threshold, its perceived importance may increase at the expense of the importance of other, simultaneously available sources of information, causing the observed deviances from parallel data patterns.

The remaining four IIDs, which showed non-linear data courses, neither showed a common pattern nor could we come up with an unambiguous interpretation of the principles according to which the corresponding athletes might have integrated the two involved sources of information. A possible explanation for these non-linear IIDs is that the athletes' mental frame of reference changed with the changing passing situations. According to IIT, athletes evaluate positional information from the perspective of their current state of goal-directedness. When this state changes (for example, because a positional change is perceived to establish the condition for the attainment of a previously unattainable goal), the perceived value of positional information will be defined relative to the newly established state. One way of testing the plausibility of this explanation would be to ask athletes about the introspective rationale of their perception. We hypothesize that substantial changes in this rationale associate with IIDs indicating non-linear information integration.

Another implication for future research is the information integration of selected athletes known for clever passing decisions and for having a good understanding of the game could be analyzed. Their IIDs could provide an indication of how higher performing athletes use positional information in perceiving the quality of passing opportunities. A final implication is that the subjective thresholds of a given set of parameters or the (relative) quality of a perceived passing opportunity, which have to be reached before a perceived opportunity becomes behaviorally

relevant, should be studied. Understanding these subjective thresholds will be an important step towards a more empirically based understanding of perceived passing affordances (Norman, 1999) and the sources of contextual information relevant to decision-making in sports. From an applied perspective, such thresholds indicate to what degree positional variables need to be constrained (defended) to prevent a passing opportunity from becoming a behaviorally relevant option for the opposing team in ball possession.

To conclude, this study is the first of its kind to analyze how athletes integrate multiple types of contextual information into subjectively perceived passing opportunities. The presented IIT approach can be adapted for research designs using VR, including other sets and ranges of contextual information, and other sports and sports situations in which the integration of information into subjective perceptions is of interest.

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The authors have declared that no competing interests exist.

## Data Availability Statement

All relevant data are within the paper.

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